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Revision F, PCN-1

Human Research Program Requirements Document

Human Research Program

Revision F, PCN-1

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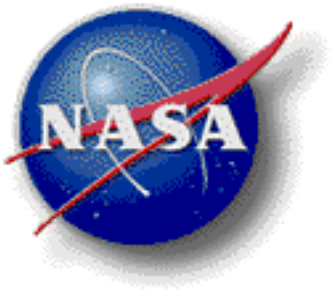

National Aeronautics and Space Administration
Johnson Space Center
Houston, Texas

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Human Research Program
Requirements Document
February 2013

PREFACE

HUMAN RESEARCH PROGRAM REQUIREMENTS DOCUMENT

This document is the Human Research Program Requirements Document. The purpose of this document is to define, document, and allocate HRP requirements. The need to produce a Program Requirements Document (PRD) is established in HRP-47051A, Human Research Program – Program Plan, and is under configuration management control of the Human Research Program Control Board (HRPCB).

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Human Research Program
Requirements Document
February 2013

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REVISION AND HISTORY PAGE

REV.	DESCRIPTION	PUB. DATE
Baseline	Initial Release (Reference per SLSDCR-HRPCB-07-006, EFF. 05-15-07) approved by the HRPCB	05-15-07
Rev A	Revision (Reference per SLSDCR-HRPCB-07-033, EFF. 07-03-07) approved outside-of-board by the HRPCB chair.	07-03-07
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Rev D	Revision (Reference per SLSDCR-HRPCB-10-011, EFF. 07-22-10) approved by the HRPCB	07-22-10
Rev E	Revision (Reference per SLSDCR-HRPCB-11-006, EFF. 04-28-11)	04-28-11
Rev E	Revision (Reference per SLSDCR-HRPCB-11-006R1, Action Number AI-HRPCB-11-011, EFF. 05-19-11)	05-19-11
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Rev F.	Revision (Reference per SLSDCR-HRPCB-12-029-R1, EFF. 12-13-12)	02-22-13
Rev F, PCN-1	Page Change Notice Revision (Reference per SLSD-HRPCB-13-011, EFF. 08-20-13)	08-20-13

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1. INTRODUCTION

1.1 PURPOSE

This document defines, documents, and allocates the Human Research Program (HRP) requirements to the HRP Program Elements. It also establishes the flow of requirements from the Human Exploration and Operations Mission Directorate (HEOMD) and the Office of the Chief Health and Medical Officer (OCHMO) down to the various HRP Program Elements to ensure that human research and technology countermeasure investments support the delivery of countermeasures and technologies that satisfy HEOMD's and OCHMO's exploration mission requirements.

1.2 SCOPE

Requirements driving HRP work and deliverables are derived from the exploration architecture as well as Agency standards regarding the maintenance of human health and performance. Agency human health and performance standards will define acceptable risk for each type and duration of exploration mission. It is critical to have the best available scientific, operational and clinical evidence in setting and validating these standards. In addition, it is imperative that the best available evidence on preventing and mitigating human health and performance risks is incorporated into exploration mission and vehicle designs. These elements form the basis of the HRP research and technology development requirements and highlight the importance of HRP investments in enabling NASA's exploration missions.

HRP requirements are derived from the following documents:

- Human Exploration and Operations Mission Directorate (HEOMD) Strategic Implementation Plan;
- NPD 1001.0A, 2011 NASA Strategic Plan
- Human Exploration and Operations Mission Directorate (HEOMD) Program Commitment Agreement (PCA) with HRP
- NASA-STD-3001, NASA Space Flight Human System Standard, Volume 1: Crew Health; and
- NASA-STD-3001, NASA Space Flight Human System Standard, Volume 2: Human Factors, Habitability and Environmental Health.

This PRD defines the requirements of the HRP which is composed of the following major Program Elements:

1. Behavioral Health & Performance (BHP),
2. Exploration Medical Capability (ExMC),
3. Human Health Countermeasures (HHC),

4. ISS Medical Projects (ISSMP),
5. Space Human Factors & Habitability (SHFH), and
6. Space Radiation (SR).

The requirements are further subdivided into the following three categories:

- Human system standards (section 4),
- Human health and performance risks (section 5), and
- Provision of enabling capabilities (section 6).

HRP requirements, as defined in this document, are allocated to the Program Office and its Program Elements. Where appropriate, the Program Elements further allocate requirements to their research and technology development portfolios. These allocations are documented in the Element Plans.

This document includes three appendices. Appendix A captures the acronyms used in this document. Appendix B encompasses additional HRP assumptions on Agency Design Reference Missions (DRMs) that HRP needs in assessing its risk posture for each of the human health and performance risks in its portfolio. Appendix C contains HRP research ratings, a tool to communicate to Agency management the seriousness of a risk to crew health and performance when applied to the mission architecture and/or mission characteristics defined for each DRM.

1.3 CHANGE AUTHORITY

This document is under Configuration Management control of the Human Research Program Control Board (HRPCB). Changes to this document will result in the issuance of change pages or a full re-issue of the document. A review of the PRD will be performed and changes made as necessary to maintain consistency with the evolving HEOMD strategies, goals, and objectives.

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents of the specified revision or the latest revision if not identified, are applicable to the extent specified herein. Inclusion of applicable documents herein does not in any way imply any order of precedence.

Table 1 – Applicable Documents

Document No.	Revision Date	Document Title
NASA-STD-3001 Vol. 1	March 2007	NASA Space Flight Human System Standards, Volume 1: Crew Health
NASA-STD-3001 Vol. 2	February 2011	NASA Space Flight Human System Standards, Volume 2: Human Factors, Habitability and Environmental Health
NPD 1001.0A	February 2011	2011 NASA Strategic Plan
HRP-XPCA	August 2012	HEOMD Program Commitment Agreement (PCA) with HRP
	Draft, October 2012	Human Exploration and Operations Mission Directorate (HEOMD) Strategic Implementation Plan
HRP-47051A	April 2009	Human Research Program – Program Plan
NPR 7120.5D	February 2012	NASA Space Flight Program and Project Management Requirements
NPD 1000.0A	August 2008	NASA Governance and Strategic Management Handbook
NPD 8500.1B	December 2007	NASA Environmental Management
NPD 8910.1B	October 2009	Care and Use of Animals
NPR 1080.1A	May 2008	Requirements for the Conduct of NASA Research & Technology (R&T)
NPR 2190.1B	December 2011	NASA Export Control Program
NPR 2810.1A	May 2006	Security of Information Technology

Table 1 – Applicable Documents

Document No.	Revision Date	Document Title
NPR 5800.1E	May 2005	Grant and Cooperative Agreement Handbook – Section C
NPR 7100.1	March 2003	Protection of Human Research Subjects w/Change 1 (07/07/08)
NPR 7120.8	February 2008	NASA Research and Technology Program and Project Management Requirements w/ Change 1 (11/24/10)
NPR 8000.4A	December 2008	Agency Risk Management Procedural Requirements
NPR 7123.1A	March 2007	NASA Systems Engineering Process and Requirements w/Change 1 (11/04/09)

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of the document.

Table 2 – Reference Documents

Document No.	Revision Date	Document Title
HRP-47053D	May 2011	Human Research Program Science Management Plan
HRP-47065D	July 2012	Human Research Program Integrated Research Plan (electronically available at: http://humanresearchroadmap.nasa.gov/)
JSC-28330D	November 2012	Space Life Sciences Directorate Configuration Control Management Plan

Table 2 – Reference Documents

Document No.	Revision Date	Document Title
N/A	N/A	HRP Evidence Base electronically available at: http://humanresearchroadmap.nasa.gov/evidence/
NPD 1000.3D	May 2012	The NASA Organization w/Change 37 (May 25, 2012)
NPD 7100.8E	December 2012	Protection of Human Research Subjects (Revalidated with admin. changes 12/18/2012)
HRP-47069C	July 2011	Unique Processes, Criteria, and Guidelines Document for HRP
S.1281	December 2005	National Aeronautics and Space Administration (NASA) Authorization Act of 2005
NASA/SP-2010-3407	January 2010	Human Integration Design Handbook
N/A	N/A	NASA Institutional Review Board Website - http://irb.nasa.gov/

3. HRP GOALS

This section reflects the HRP Goals and Objectives described in the HRP Program Commitment Agreement and HRP-47051, Human Research Program – Program Plan.

3.1 THE GOAL OF THE HRP IS TO PROVIDE HUMAN HEALTH AND PERFORMANCE COUNTERMEASURES, KNOWLEDGE, TECHNOLOGIES, AND TOOLS TO ENABLE SAFE, RELIABLE, AND PRODUCTIVE HUMAN SPACE EXPLORATION. THE SPECIFIC OBJECTIVES OF THE HRP ARE:

3.1.1 Develop capabilities, necessary countermeasures, and technologies in support of human space exploration, focusing on mitigating the highest risks to crew health and performance. Enable the definition and improvement of human spaceflight medical, environmental and human factors standards.

3.1.2 Develop technologies that serve to reduce medical and environmental risks, to reduce human systems resource requirements (mass, volume, power, data, etc.), and to ensure effective human-system integration across exploration mission systems.

3.1.3 Ensure maintenance of Agency core competencies necessary to enable risk reduction in the following areas: space medicine; physiological and behavioral effects of long-duration spaceflight on the human body; space environmental effects (including radiation) on human health and performance; and space human factors.

4. HRP REQUIREMENTS RELATED TO HUMAN SYSTEM STANDARDS

4.1 THE HUMAN RESEARCH PROGRAM (HRP) SHALL ENABLE THE DEVELOPMENT AND VALIDATION OF NASA'S HEALTH, MEDICAL, HUMAN PERFORMANCE, AND ENVIRONMENTAL STANDARDS IN TIME FOR EXPLORATION MISSION PLANNING AND DESIGN.

Rationale: A first step in mitigation of human health and performance risks is the establishment of spaceflight human system standards. These standards are designed to address acceptable levels of human health and performance risks for exploration missions of varying complexity and duration. The NASA Chief Health & Medical Officer (CHMO) has established an initial set of standards that serves to guide the HRP in the expansion of its evidence base regarding human spaceflight health and performance risks. HRP sponsors research and technology development enabling modification or development of OCHMO maintained standards.

Several different types of standards have been established by the CHMO and documented in NASA-STD-3001, NASA Space Flight Human Systems Standards, Vol. 1 and Vol. 2. Specifically, the standards sets are listed below.

- Fitness-for-duty standards for maintaining the physiological and behavioral parameters necessary to perform the required tasks;
- Permissible outcome limits for the changes in health outcomes that are potentially affected by long-term exposure to the space environment;
- Permissible exposure limits for managing risks by controlling human exposure;
- Levels of care standards for guiding medical capabilities needed to respond to a medical contingency during exploration missions; and
- Human factors, habitability, and environmental standards to guide the development of spacecraft and systems so as to alleviate human health and performance impacts.

The HRP requirements necessary to ensure the best possible evidence base in order to enable the development of standards are included in this section:

4.1.1 The HHC shall perform the research necessary to enable the development and validation of the Fitness for Duty Aerobic Capacity standard.

4.1.2 The HHC shall perform the research necessary to enable the development and validation of the Fitness for Duty Sensorimotor standard.

4.1.3 The HHC shall perform the research necessary to enable the development and validation of the Fitness for Duty Hematology and Immunology standard.

4.1.4 The HHC shall perform the research necessary to enable the development and validation of the Permissible Outcome Limit for Nutrition standard.

4.1.5 The HHC shall perform the research necessary to enable the development and validation of the Permissible Outcome Limit for Muscle Strength standard.

4.1.6 The HHC shall perform the research necessary to enable the development and validation of the Permissible Outcome Limit for Microgravity Induced Bone Mineral Loss Performance standard.

4.1.7 The HHC shall perform the research and ensure the technology availability to ensure the Levels of Care standards in pharmacology can be met for each exploration mission.

4.1.8 The HHC shall perform the research and technology development necessary to enable the development of the Extravehicular Activity (EVA) sections of NASA-STD-3001, NASA Space Flight Human Systems Standard, Vol. 2: Human Factors, Habitability and Environmental Health.

4.1.9 The BHP shall perform the research necessary to enable the development and validation of the Fitness for Duty Behavioral Health and Cognition standard.

4.1.10 The BHP shall perform the research necessary to enable the development of the Circadian Entrainment and Workload sections of NASA-STD-3001, Vol. 2.

4.1.11 The SR shall perform the research necessary to enable development and validation of the Space Permissible Exposure Limit for Space Flight Radiation Exposure standard.

4.1.12 The SR shall perform the research and technology development necessary to enable the development of the Radiation sections of NASA-STD-3001, Vol. 2.

4.1.13 The SHFH shall perform the research necessary to enable development and validation of the Permissible Exposure Limit Lunar Dust Inhalation standard.

4.1.14 The ExMC shall perform the research necessary to enable development and validation of Crewmember Selection and Retention Criteria.

4.1.15 The SHFH shall perform the research and technology development to enable documentation and validation of the environmental and human

factors standards within NASA-STD-3001, NASA Space Flight Human Systems Standard, Vol. 2, and the Human Integration Design Handbook.

4.1.16 The HHC shall perform research and technology development to enable the development and validation of the Fitness for Duty standards to Vision Alterations.

4.1.17 The HHC shall perfrom research and technology development to enable the development and validation of Occupant Protection standards in NASA-STD-3001, Vol. 2.

4.1.18 The HHC shall perform the research necessary to enable the development and validation of the Permissible Outcome Limit standards for Decompression Sickness (DCS).

5. HRP REQUIREMENTS RELATED TO HUMAN HEALTH & PERFORMANCE RISKS

The primary objective of the HRP is to enable prevention and mitigation of human health and performance risks to facilitate successful completion of exploration missions, and preservation of astronaut health over the long-term.

Evidence Base

The HRP Evidence Base is a collection of evidence-based risk reports, one for each human health and performance risk listed in this section and for which implementation activities are listed in HRP-47065, HRP Integrated Research Plan. The Evidence Base provides a current record of the state of knowledge, from research and operations, for each of the risks, written for the scientifically educated, non-specialist reader. The risk evidence reports are posted on the Human Research Roadmap Website - http://humanresearchroadmap.nasa.gov/evidence/.

As shown in Figure 1, the development of HRP content has been formulated around the management architecture of:

Figure 1: HRP Management Architecture

Evidence of spaceflight-related issues is used to define risks to crew health and performance. The risks are due to gaps in our knowledgebase. HRP funds tasks to address and close these gaps, and provides deliverables to NASA programs to address identified issues.

Human System Risk Board

The CHMO is the Health & Medical Technical Authority (HMTA) per NPD 1000.3D, The NASA Organization. The CHMO appoints the HMTA Chief Medical Officer (CMO) designee at each NASA center (as appropriate). The JSC CMO established the Human System Risk Board (HSRB) to ensure a consistent, integrated process is established and maintained for managing human system risks.

Per HRP-47051A, HRP Program Plan, the Bioastronautics Roadmap (BR) was used as a starting-point reference document. The BR initially captured the human system risks associated with exploration missions. However, it did not capture the level of detail necessary to prioritize across disciplines or compare strategies for a given risk across mission architectures and resources. The JSC CMO developed the Risk Management Analysis Tool (RMAT) to fill this gap and facilitate discussion and decisions by the HSRB.

The RMAT is used as a communication tool to understand human system risks and compare standards, requirements, mitigation strategies, etc. against known

mission architectures and resources. The RMAT collects the appropriate information to allow decision-makers to develop mitigation strategies for the highest priority human risks for each mission architecture. The RMAT format reviews human system risks in terms of consequence, likelihood, uncertainty, contributing factors, and proposals for mitigating the risks and reviews each risk in terms of multiple mission architectures (ISS 6-month mission, ISS 12-month mission, Lunar sortie, Lunar outpost, Asteroid and Mars Mission).

If the HSRB determines there is sufficient evidence for a risk but additional research is required to understand or mitigate the risk, it is assigned to the applicable Program or individual responsible for owning the risk. If assigned to the HRP, the program will complete an analysis of the risk and develop a research plan to further understand the risk, inform the standards, or develop mitigation or monitoring strategies for the risk. The process for changing human health and performance risks is documented in HRP-47069, Human Research Program Unique Processes, Criteria, and Guidelines (UPCG) document.

Risks in the HRP Portfolio

The current HRP human health and performance risks and applicable HRP Element assignment are listed in Table 3. The risk content in Table 3 contains the following information:

1. Risk Title: Top level wording used to describe the risk.
2. Risk Short Title: An abbreviation of the Risk Title
3. Assigned Element
4. Links to the Integrated Research Plan (IRP) Human Research Roadmap (HRR)

Table 3 – Exploration Missions Human Health and Performance Risks

HRP Element	Risk Title (Short Title)
HHC	Risk of Orthostatic Intolerance During Re-Exposure to Gravity (Short Title: OI). Link to HRR
HHC	Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo) Link to HRR
HHC	Risk Factor of Inadequate Nutrition (Short Title: Nutrition) Link to HRR
HHC	Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems (Short Title: EVA) Link to HRR
HHC	Risk of Inadequate Performance Due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle) Link to HRR

Table 3 – Exploration Missions Human Health and Performance Risks

HRP Element	Risk Title (Short Title)
HHC	Risk of Renal Stone Formation (Short Title: Renal) Link to HRR
HHC	Risk of Bone Fracture (Short Title: Fracture) Link to HRR
HHC	Risk of Intervertebral Disc Damage (Short Title: IVD) Link to HRR
HHC	Risk of Cardiac Rhythm Problems (Short Title: Arrhythmia) Link to HRR
HHC	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Short Title: Aerobic) Link to HRR
HHC	Risk of Crew Adverse Health Event Due to Altered Immune Response (Short Title: Immune) Link to HRR
HHC	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with Space Flight (Short Title: Sensorimotor) Link to HRR
HHC	Risk of Clinically Relevant Unpredicted Effects of Medication (Short Title: Pharm) Link to HRR
HHC	Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (Short Title: VIIP) Link to HRR
HHC	Risk of Decompression Sickness (Short Title: DCS) Link to HRR
HHC	Risk of Injury from Dynamic Loads (Short Title: Occupant Protection)
SHFH	Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System (Short Title: Food) Link to HRR
SHFH	Risk of Inadequate Human-Computer Interaction (Short Title: HCI) Link to HRR
SHFH	Risk of Performance Errors Due to Training Deficiencies (Short Title: Train) Link to HRR
SHFH	Risk of Inadequate Design of Human and Automation/Robotic Integration (Short Title: HARI) Link to HRR
SHFH	Risk of Inadequate Critical Task Design (Short Title: Task) Link to HRR
SHFH	Risk of Adverse Health Effects of Exposure to Dust and Volatiles During Exploration of Celestial Bodies (Short Title: Dust) Link to HRR
SHFH	Risk of an Incompatible Vehicle/Habitat Design (Short Title: Hab) Link to HRR

Table 3 – Exploration Missions Human Health and Performance Risks

HRP Element	Risk Title (Short Title)
SHFH	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions (Short Title: Microhost) Link to HRR
ExMC	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities (Short Title: ExMC) Link to HRR
BHP	Risk of Adverse Behavioral Conditions and Psychiatric Disorders (Short Title: Bmed) - Reference RMATs for Risk of Adverse Behavioral Conditions, and Risk of Psychiatric Disorders Link to HRR
BHP	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep) Link to HRR
BHP	Risk of Performance Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Short Title: Team) Link to HRR
SR	Risk of Radiation Carcinogenesis (Short Title: Cancer) Link to HRR
SR	Risk of Acute Radiation Syndromes Due to Solar Particle Events (Short Title: ARS) Link to HRR
SR	Risk of Acute or Late Central Nervous System Effects from Radiation Exposure (Short Title: CNS) Link to HRR
SR	Risk of Degenerative Tissue or other Health Effects from Radiation Exposure (Short Title: Degen) Link to HRR

5.1 THE HRP SHALL QUANTIFY THE HUMAN HEALTH AND PERFORMANCE RISKS ASSOCIATED WITH HUMAN SPACEFLIGHT FOR EXPLORATION MISSIONS.

Rationale: In many cases, there is a large uncertainty associated with the risk due to lack of controlled spaceflight (or ground analog) experimental evidence. This HRP requirement is to quantifiably describe the likelihood and consequences of the risks. The uncertainties associated with these quantities should be narrowed to the target values identified by each standard or to the greatest extent practical to facilitate proper decisions for exploration hardware and software design and mission design.

5.1.1 The HRP Science Management Office (SMO) shall develop ways to improve estimates of the integrated human health and performance risk associated with human spaceflight for exploration missions.

Rationale: The overall risk assessment extends beyond a “list” of risks. The risks often have inter-relationships and interdependencies. The SMO must evaluate the risks to identify and quantify these inter-relationships and interdependencies, and provide an assessment of the total risk to the human system for spaceflight. This will help focus HRP efforts and ensure proper decision making.

5.1.2 The BHP shall quantify the BHP-applicable Risks identified in Table 3.

5.1.3 The ExMC shall quantify the ExMC-applicable Risks identified in Table 3.

5.1.4 The HHC shall quantify the HHC-applicable Risks identified in Table 3.

5.1.5 The SHFH shall quantify the SHFH-applicable Risks identified in Table 3.

5.1.6 The SR shall quantify the Space Radiation-applicable Risks identified in Table 3.

5.2 THE HRP ELEMENTS SHALL DEVELOP COUNTERMEASURES AND TECHNOLOGIES TO PREVENT OR MITIGATE ADVERSE OUTCOMES OF HUMAN HEALTH AND PERFORMANCE RISKS.

Rationale: Each risk is written with respect to an adverse outcome. The intent of the HRP is to prevent the adverse outcome from occurring. If that cannot be done, the intent is to develop and validate novel countermeasures (devices, drugs, procedures, etc.) that will mitigate the adverse outcome. In this context, “mitigate” means “reduce the severity or reduce the probability of the adverse outcome.”

5.2.1 The BHP shall develop countermeasures and technologies to prevent or mitigate adverse outcomes of human health and performance risks relevant to BHP (see Table 3).

5.2.2 The ExMC shall develop countermeasures and technologies to prevent or mitigate adverse outcomes of human health and performance risks relevant to ExMC (see Table 3).

5.2.3 The HHC shall develop countermeasures and technologies to prevent or mitigate adverse outcomes of human health and performance risks relevant to HHC (see Table 3).

5.2.4 The SHFH shall develop countermeasures, technologies, tools, and design guidelines to prevent or mitigate adverse outcomes of human health and performance risks relevant to SHFH (see Table 3).

5.2.5 The SR shall develop countermeasures and technologies to prevent or mitigate adverse outcomes of human health and performance risks relevant to Space Radiation (see Table 3).

5.3 THE HRP ELEMENTS SHALL DEVELOP COUNTERMEASURES AND TECHNOLOGIES TO MONITOR AND TREAT ADVERSE OUTCOMES OF HUMAN HEALTH AND PERFORMANCE RISKS.

Rationale: If a risk cannot be mitigated adequately, the human must be monitored for indicators of an adverse outcome, and treatment and or countermeasures should be developed.

5.3.1 The BHP shall develop countermeasures and technologies to monitor and treat adverse outcomes of human health and performance risks relevant to BHP (see Table 3).

5.3.2 The ExMC shall develop countermeasures and technologies to monitor and treat adverse outcomes of human health and performance risks relevant to ExMC (see Table 3).

5.3.3 The HHC shall develop countermeasures and technologies to monitor and treat adverse outcomes of human health and performance risks relevant to HHC (see Table 3).

5.3.4 The SHFH shall develop countermeasures and technologies to monitor and treat adverse outcomes of human health and performance risks relevant to SHFH (see Table 3).

5.3.5 The SR shall develop countermeasures and technologies to monitor indicators of adverse outcomes of human health and performance risks relevant to Space Radiation (see Table 3).

6. HRP REQUIREMENTS RELATED TO PROVISION OF ENABLING CAPABILITIES

6.1 THE HRP SHALL PROVIDE THE ENABLING CAPABILITY TO FACILITATE HUMAN SPACE EXPLORATION WITH RESPECT TO THE HUMAN SYSTEM.

Rationale: Ensuring Human exploration requires some infrastructure or activities that do not readily fall into a specific research and technology development category. The requirements below are intended to provide NASA with the necessary infrastructure or capabilities to implement the research and technology work required to update, inform, and validate standards and to address the risks relevant to human exploration.

In the course of research and technology development, each HRP Element may encounter the need to perform studies in a ground-based space analog environment (e.g., bed-rest facility, Antarctica). Each Element, with support from ISSMP, is responsible for the selection and/or validation of the appropriate analogs and the necessary planning, integration, and execution. Large resource commitments to analog facilities must be reflected in the Element Research Plan so that the cost-benefit to the HRP is clear.

6.1.1 The ISSMP shall plan, integrate, and execute HRP research tasks requiring access to space to address standards or reduce or eliminate human health and performance risks.

Rationale: Access to space research platforms [the ISS and all ISS visiting vehicles that transport crew and/or cargo to and from the ISS] is required to study and/or validate many of the items in sections 4.0 and 5.0. The ISSMP serves as the service to integrate across all other HRP Elements, and optimize the research plans requiring access to space. The ISSMP provides the interface to the spaceflight programs to ensure that the research is properly planned, integrated, and executed with the required data returned to the investigator.

6.1.2 The SMO and ExMC shall provide a data integration and management function to ensure proper handling of and access to HRP data.

Rationale: Access to data is critically important to advancing the state of knowledge of the human system in space. A data integration and management function includes the proper archiving of historical research data [e.g., the Life Sciences Data Archive (LSDA)] and organizing medical and research data to provide proper security levels, allow access by query, and to provide tools to allow analysis of evidence (e.g., Integrated Medical Model and the Integrated Medical Evidence Database).

6.2 THE HRP SHALL ENSURE PRESERVATION AND MAINTENANCE OF CORE TECHNICAL CAPABILITY AND EXPERTISE IN HUMAN RESEARCH AND TECHNOLOGY DEVELOPMENT.

Rationale: The core competencies are those which are necessary to maintain and nurture an understanding of the existing evidence base regarding risks and adverse outcomes to humans due to spaceflight. This core competency involves sustaining and maintaining a dedicated scientific and management workforce and a robust external scientific community. It also requires an adequate testing laboratory physical-plant capability. Preservation and maintenance of this capability is necessary to provide stability over the multi-decadal implementation of the vision for space exploration. This core competency is necessary to facilitate the following:

Strategic planning. Identification and prioritization of the risks to the human system and development of long-range plans to quantify, prevent, mitigate, and treat the adverse outcomes requires competency of both the internal and external community to ensure proper direction to the research community for focusing their effort.

Acquisition development, planning, and execution. Acquisition of research and technology development is an inherently governmental function that requires core expertise within the civil service to ensure that the U.S. Government remains a “smart buyer” with respect to research and technology development for the human system.

Operations support for near-real time and real-time operational decisions involving the human system and environment. Laboratory facilities and the expertise to run them and interpret results are necessary to support an ongoing evaluation of the human system response to the space environment and to support the medical operations function during a mission. This involves the internal community, and to some extent, the external community where uniquely specialized expertise must be sought.

The requirement is written at the HRP level and not specifically allocated to the Program Elements. However, the Program Elements shall provide inputs regarding their core competency needs and issues. As part of the annual Planning, Programming, Budgeting, and Execution (PPBE) process, Program Management will review the core technical capability of the Program Elements and adjust where appropriate.

6.3 EACH HRP ELEMENT SHALL ENSURE THAT THEIR PROCESSES AND PRODUCTS COMPLY WITH THE NASA POLICY DIRECTIVES AND NASA PROCEDURAL REQUIREMENTS LISTED IN THE TABLE OF APPLICABLE DOCUMENTS IN SECTION 2.1.

Rationale: The Table of applicable documents includes the NASA Policy Directives (NPD) and NASA Procedural Requirements (NPR) specifically

referenced by HRP-47051, HRP Program Plan. This requirement explicitly states which NPR and NPD are applicable to the HRP and ensures that the requirement is flowed down to the Program Element level. Identification of specific NPR/NPD applicability falls upon each individual Element/Project when the Project Plan is defined. The intent of this requirement is to ensure HRP compliance with these documents within the normal processes and product development ongoing in the HRP.

6.4 THE HRP ELEMENTS SHALL DEVELOP METHODS AND TECHNOLOGIES TO REDUCE HUMAN SYSTEMS RESOURCE REQUIREMENTS (MASS, VOLUME, POWER, DATA, ETC.).

Rationale: Methods and technologies that reduce the human systems resource requirements for mass, volume, power, data, etc. must be developed to reduce the overall exploration resource requirements. Each HRP research element must focus the research on producing countermeasures and technologies that fit within the extremely limited resource envelopes anticipated for the exploration mission. An example is the reduction in time dedicated to exercise prescriptions. Present exercise prescriptions present a large burden on the overall mission timeline.

6.4.1 The HHC shall develop methods and technologies to reduce human systems resource requirements (mass, volume, power, crew time, etc.).

6.4.2 The BHP shall develop methods and technologies to reduce human systems resource requirements (mass, volume, power, crew time, etc.).

6.4.3 The SR shall develop methods and technologies to reduce human systems resource requirements (mass, volume, power, crew time, etc.).

6.4.4 The SHFH shall develop methods and technologies to reduce human systems resource requirements (mass, volume, power, crew time, etc.).

6.4.5 The ExMC shall develop methods and technologies to reduce human systems resource requirements (mass, volume, power, crew time, etc.).

APPENDIX A – ACRONYMS AND ABBREVIATIONS

AM	Ascent Module
ARED	Advanced Resistive Exercise Device
ARS	Acute Radiation Sickness
BHP	Behavioral Health & Performance
BMD	Bone Mineral Density
Bmed	Behavioral Conditions & Psychiatric Disorders
BR	Bioastronautics Roadmap
CLiFF	Clinical Findings Forum
CHMO	Chief Health & Medical Officer
CMO	Chief Medical Officer
CNS	Central Nervous System
DCS	Decompression Sickness
Degen	Degenerative
DM	Descent Module
DRM	Design Reference Mission
DXA	Dual-energy X-ray Absorptiometry
ECLSS	Environmental Control and Life Support System
e.g.	For Example
EDL	Entry, Descent, and Landing
EVA	Extravehicular Activity
ExMC	Exploration Medical Capability
GCR	Galactic Cosmic Rays
Hab	Habitat
HARI	Human & Automation/Robotic Integration
HCI	Human-Computer Interaction
HEOMD	Human Exploration and Operations Mission Directorate
HHC	Human Health Countermeasures
HMTA	Health & Medical Technical Authority
HRP	Human Research Program
HRPCB	Human Research Program Control Board
HRR	Human Research Roadmap
HSRB	Human System Risk Board
HZE	High energy particles
IMM	Integrated Medical Model
IRP	Integrated Research Plan
ISS	International Space Station
ISSMP	ISS Medical Projects
IVD	Intervertebral Disc
JBMR	Journal of Bone and Mineral Research
JSC	Johnson Space Center
LEO	Low Earth Orbit
LET	Linear Energry Transfer
LSDA	Life Sciences Data Archive
MCC	Mission Control Center
Microhost	Host-Microorganism
MPCV	Multi-Purpose Crew Vehicle
MRID	Medical Requirements Integration Documents

NASA	National Aeronautics and Space Administration
NEA	Near-Earth Asteroid
NPD	NASA Procedural Directive
NPR	NASA Procedural Requirement
OCHMO	Office of the Chief Health and Medical Office
OI	Orthostatic Intolerance
Osteo	Osteoporosis
PCA	Program Commitment Agreement
PEL	Permissible Exposure Limit
Pharm	Pharmacology
PPBE	Planning, Programming, Budgeting, and Execution
PRD	Program Requirements Document
PVT	Psychomotor Vigilance Task
QCT	Quantitative Computed Tomography
QT	Q wave/T wave interval
R&T	Research and Technology
RMAT	Risk Mitigation Analysis Tool
SHFH	Space Human Factors & Habitability
SMO	Science Management Office
SPDM	Special Purpose Dexterous Manipulator
SR	Space Radiation
SSRMS	Space Station Remote Manipulation System
TBS	To Be Specified
TEI	Trans-Earth Insertion
U.S.	United States
UPCG	Unique Processes, Criteria, and Guidelines
VIIP	Visual Impairment/Intracranial Pressure
Vol.	Volume

APPENDIX B – HRP DESIGN REFERENCE MISSION DESCRIPTIONS AND ASSUMPTIONS

The HRP focuses its research investment on investigating and mitigating the highest risks to astronaut health and performance in support of exploration missions. The program also develops and matures operations concepts that will inform requirements for the design and operation of space vehicles and habitats needed for exploration missions. For each crew health and performance risk in the HRP portfolio, an assessment is performed to understand human system risks, and compare standards, requirements, mitigation strategies, etc. against defined exploration mission scenarios.

The exploration missions currently considered include the International Space Station (ISS), lunar, near Earth objects/asteroids, and Mars missions. Although these mission types involve some of the same human health and performance challenges, each also includes specific challenges that depend on the nature of the mission and the mission development schedule. The HRP research and technology development plan/schedule/framework is phased to supply appropriate deliverables in time to meet the challenges of each mission type.

HRP relies on the Design Reference Missions (DRMs) which provide a framework to identify key capabilities and important guiding drivers and assumptions, thus enabling the HRP to focus its research questions on topics highly relevant to NASA's future activities. However, in some cases, the details provided by the agency DRMs are not specific enough to encompass additional assumptions that HRP needs to make in assessing its risk posture for each of the risks in its portfolio. These additional assumptions are listed in this section together with the agency DRM information to define the complete set of mission guidelines that the HRP utilizes in its research and risk assessment. These DRMs provide the bounding conditions and trade space for defining future spaceflight capabilities and key performance drivers required to achieve mission objectives.

HRP ISS-12 DRM Assumptions

Crew Size
The crew is composed of two (2) crewmembers.

Mission Duration
The crew will be stationed on the ISS for a minimum duration of 12 months and will have interaction with the additional four (4) ISS crewmembers that will be in 6-month rotation cycle.

Early Termination of Mission
Crew can return to Earth within 24 hours.

Role of Ground Support / Mission Control Center (MCC)
Communications is nearly real-time. Ground personnel will perform many of the on-board operations, including monitoring and controlling some systems during the crew sleep period, operating the Special Purpose Dexterous Manipulator (SPDM), and assisting the crew in operating the Space Station Remote Manipulation System (SSRMS). Ground personnel will manage and replan schedule as necessary. Ground personnel will provide training / training materials as needed. For example, medical evaluations using ultrasound can be performed with real time support from a flight surgeon.

Resupply and Sample Return
There will be at least 1-2 resupply missions during the 12 months, which can provide consumables and spare parts. Samples can be returned for ground analysis for toxic and microbial analysis.

Crew Habitation
The crewmembers will use the Soyuz spacecraft as transportation to/from ISS. Between launch and docking on the ISS, the crew will spend about 2 days in the Soyuz vehicle prior to arrival on ISS. The departure from ISS will likely take approximately 8-10 hours before returning back to Earth. While on the ISS, the crewmembers will have access to all facilities and capabilities that the ISS vehicle provides for all operations. The habitat consists of multiple modules launched over a several year period. The volume is approximately 388 cubic meters.

Crew Timeline/Activities
There are two types of activities in which the crew will be involved on a daily basis during their ISS stay. The first activity type is focused on what the crew would do to live in space: Crew Sleep, pre/post sleep activities to include galley operations and personal hygiene, exercise, review/development of crew planned activities/schedule. The second activity type is focused on science/payload operations and vehicle system management/maintenance as required and

interaction with ground control center. During their stay, the crew may be required to do up to four (4) EVAs per crewmember for the entire 12 months.

Exercise Equipment

The crew will maintain their physiological health with the same capability as is currently provided to the ISS crew and defined in the NASA-STD-3001, Vol. 1: Crew Health.

HRP Constraints/Implied Requirements

Adequate vehicle or habitat shielding, dosimetry, and operational procedures in place to prevent exposures above 30-day permissible dose limits. Requirements for the on-orbit phase of HRP studies that collect in-flight data will need to be re-phased for a one year vs. six month duration.

Pre/Post Mission Assumptions

Some HRP investigations will allow flexibility in their requirements for significant crew time in the immediate post-flight measurements (R+1 week especially). Medical testing conducted during the first week postflight will occur as usual to assure the health of the crewmember. Sharing of these data will be possible with crewmember consent. Requirements with minimal crew time commitments may still be performed, such as blood, urine and saliva collections.

HRP Lunar (Outpost and Sortie) Mission DRM Assumptions

Crew Size
The crew is composed of four (4) crewmembers comprised of both male and female astronauts.

Mission Duration
The total mission duration can range from approximately 3 weeks for a Sortie mission to approximately 6 months for an Outpost mission. The transit time to/from the Moon will be approximately 4 days. Surface time for a Sortie mission will be approximately 2 weeks and an Outpost mission will last approximately 6 months.

Early Termination of Mission
Crew can return to Earth within 4-5 days.

Role of Ground Support / MCC
Communication delay is close to the length for which closed loop real time sensitive operations are possible. Delays will impact high consequence activities such as telemedicine, or robotic operations when the robots are near the habitat or an EVA crewmember. Ground personnel will be able to provide replanning and training, but will not be able to 'watch over the shoulder' for crewmembers performing robotics operations. Ground support will be able to monitor systems during crew sleep periods, and provide critical information from the 'back room' in near real-time.

Crew Habitation
Crew vehicle capabilities include the Multi-Purpose Crew Vehicle (MPCV) crew module and a Lunar Lander that provide all of the crew capabilities required for living and operating in space and on the lunar surface. The Lunar Lander provides transportation for crew members to and from the lunar surface and supports crew members for short duration stays on the lunar surface. The Lunar Lander used for a Sortie mission will be a two-module configuration consisting of the Descent Module (DM) and the Ascent Module (AM) and suit ports. The AM includes suit ports and a side hatch opening to the Lunar Lander deck.
In support of a Lunar Outpost mission, the Lunar Lander also has a three-module vehicle configuration for extended stays consisting of the DM, the AM, and a suit lock/suit port module. The suit ports minimize the time required for the crew members to don suits and begin surface EVA, and minimize atmosphere losses.

Sample Return

All monitoring for microbial or toxic hazards must be performed on board. Sample return capability may be available for a very limited amount driven by overall return vehicle stowage capability.

Crew Timeline/Activities

There are two types of activities in which the crew will be involved on a daily basis during transit time to/from Moon. The first activity type is focused on what the crew would do to live in space: crew sleep, pre/post sleep activities to include galley operations and personal hygiene, exercise, review/development of crew planned activities/schedule. The second activity type is focused on science/payloads operations (dependent on upmass capabilities), vehicle system management/maintenance, as required, and interaction with ground control center. During transit time, there will be no planned or contingency EVAs performed.

Communication Delays

Any communication delays between the crew and the ground control center will be on the order of a couple of seconds while on the lunar surface.

Lunar Surface Operations

During the entire Lunar surface stay, the four crewmembers are expected to perform multiple EVAs. During an EVA sortie, the crew has the capability to perform EVAs with all crew members egressing from the vehicle through an airlock or suitport provided capability. Performing EVAs in pairs with all four crew members on the surface maximizes the scientific and operational value of the mission.

Crew Logistics/Food

There will not be any mission resupply to replenish the crew with logistical requirements during the entire mission. All consumables and spare parts must be provided at the start of the mission and available from the habitable volume. The MPCV and Lunar Lander module will have a food galley with the required capabilities for the crew to prepare their meals. The majority of the food storage will be contained in the Lunar Lander module under the required food storage constraints.

Exercise Equipment

The crew will maintain their physiological health with the same capability as is currently provided to the ISS crew and defined in NASA-STD-3001, Vol. 1.

HRP Constraints/Implied Requirements

Adequate vehicle or habitat shielding, dosimetry, and operational procedures in place to prevent exposures above 30-day permissible dose limits.

Pre/Post Mission Assumptions

TBD post-flight Baseline Data Collection will still be required, similar to ISS post-flight protocols.

HRP Near-Earth Asteroid (NEA) DRM Assumptions

Crew Size
The crew is composed of three (3) crewmembers comprised of both male and female astronauts.

Mission Duration
The total mission duration from launch to crew return is assumed to be approximately 1 year. This includes approximately 6 months of transit time from Earth to NEA, a 30-day stay at NEA, and another 6-month transit time from NEA back to Earth.

Early Termination of Mission
While an early crew return is possible for the ISS-12 and Lunar missions, at this time it is assumed the crew cannot return early from a NEA mission. As more information about NEA missions is determined, the possibility for early termination of the mission will be more clear.

Role of Ground Support / MCC
A communication delay of up to 30-seconds is too great to enable real-time control of critical operations, such as are done on ISS for SPDM and SSRMS. Ground support will be provided in 'batch mode' rather than real time. Real-time flight surgeon support of medical evaluations using ultrasound or other technologies will not be possible. Training material will be able to be sent in batch mode, but interactive training with immediate feedback from ground support will not be possible. Ground support will be able to monitor systems during crew sleep periods, and provide information in batches.

Crew Habitation
Mission duration drives the need for the crew habitation capabilities for the entire mission. Crew vehicle capabilities include the MPCV crew module, and a crew habitation module that provides all of the crew capabilities required for living and operating in space, which include all available resources required by the crew for the entire mission. The habitable volume shall be large enough and laid out to execute the necessary tasks and to provide a psychologically acceptable space for the long period of confinement. The habitation/vehicle configuration provides:

- Sensory stimulation (e.g., variable lighting, virtual reality) that offsets the physically and socially monotonous environment.
- Monitoring systems that unobtrusively track cognitive performance deficits, stress, fatigue, anxiety, depression, behavioral health, task performance, teamwork, and psychosocial performance.
- Devices that mitigate the effects of fatigue, circadian misalignment, and work-overload.
- Communication tools that offset communication delays ranging from seconds to minutes.

The habitat consists of multiple modules, each of which will be launched on a single disposable rocket and assembled in orbit.

Sample Return
All monitoring for microbial or toxic hazards must be performed on board. No sample return will be possible.

Crew Timeline/Activities
There are two types of activities in which the crew will be involved with on a daily basis during transit time to/from a NEA. The first activity type is focused on what the crew would do to live in space: crew sleep, pre/post sleep activities to include galley operations and personal hygiene, exercise, review/development of crew planned activities/schedule. The second activity type is focused on science/payload operations and vehicle system management/maintenance as required and interaction with ground control center. During transit time, there will be no planned or contingency EVAs performed.

Communication Delays
Expect communication delays between the crew and the ground control center to increase from zero during Low Earth Orbit (LEO) to up to approximately 30 seconds at NEA arrival, with the same duration impact during return to Earth. Due to the communication delay, the crew is expected to perform autonomous operations as required.

NEA Surface Operations
During the entire 30-day stay on the NEA surface, the crew is expected to perform multiple EVAs. During the EVA activities, the crew will be augmented with robotic support. The crew will also be able to perform NEA surface operations only utilizing their robotics capabilities. The Asteroid destination is assumed to be about 500 meters in length with a dusty rubble pile and volatiles. The vehicle design will provide a physical containment area for surface samples to isolate the crewmembers from any Asteroid surface materials that they may bring back to Earth. Surface operations will subject the EVA crew to a possible microgravity field while on the surface.

Crew Logistics/Food
There will not be any mission resupply to replenish the crew of logistical requirements during the entire mission. All consumables and spare parts must be provided at the start of the mission and available from the habitable volume. The habitation module will have a food galley with the required capabilities for the crew to prepare their meals. Food storage will be contained in the habitation module under the required food storage constraints.

Exercise Equipment
The crew will have the capability to maintain their physiological health per the requirements defined in the NASA-STD-3001, Vol. 1.

HRP Constraints/Implied Requirements

Adequate vehicle or habitat shielding, dosimetry, and operational procedures in place to prevent exposures above 30-day permissible dose limits.

Pre/Post Mission Assumptions

TBD post-flight Baseline Data Collection will still be required, but protocols will need to consider degree of crew de-conditioning after a 1-yr mission.

HRP Mars DRM Assumptions

Crew Size
The crew is composed of six (6) crewmembers comprised of both male and female astronauts.

Mission Duration
The Mars Exploration DRM, often referred to as long-stay missions, is characterized by the need to minimize the exposure of the crew to the deep-space radiation and zero-gravity environment while, at the same time, maximizing the scientific return from the mission. This is accomplished by taking advantage of optimum alignment of Earth and Mars for both the outbound and return trajectories, and by varying the stay time on Mars, rather than forcing the mission through non-optimal trajectories. This approach allows the crew to transfer to and from Mars on relatively fast trajectories, on the order of 6 months, while allowing them to stay on the surface of Mars for a majority of the mission, on the order of 18 months. The total mission duration from launch to crew return is assumed to be approximately 3 years.

Early Termination of Mission
Crew cannot return to Earth early.

Role of Ground Support / MCC
The communication delay is too great to enable real-time control of critical operations, such as are done on ISS for SPDM and SSRMS. Ground support will be provided in 'batch mode' rather than real-time. Flight surgeon support of medical evaluations using ultrasound or other technologies will be 'batch' mode; guiding the placement of probes real-time will not be possible. Training material will be able to be sent in batch mode, but interactive training with immediate feedback from ground support will not be possible. Ground support will not be able to monitor time-critical systems during crew sleep periods. Back room support will be significantly delayed. The crew must be able to stabilize systems for all contingencies for up to 44 minutes without any ground assistance.

Crew Habitation
Mission duration drives the need for the crew habitation capabilities for the entire mission. Crew vehicle capabilities include the MPCV crew module, a crew habitation module that provides all of the crew capabilities required for living and operating in space, and a cargo module with all available resources required by the crew for the entire mission. The habitable volume must be large enough and laid out to execute the necessary tasks and to provide a psychologically acceptable space for the long period of confinement. The habitation/vehicle configuration provides:

- Sensory stimulation (e.g., variable lighting, virtual reality) that offsets the physically and socially monotonous environment.
- Monitoring systems that unobtrusively track cognitive performance deficits, stress, fatigue, anxiety, depression, behavioral health, task performance, teamwork, and psychosocial performance.
- Devices that mitigate the effects of fatigue, circadian misalignment, and work-overload.
- Communication tools that offset communication delays ranging from seconds to minutes.

Crew Timeline/Activities

There are two types of activities in which the crew will be involved with on a daily basis during transit time to/from Mars. The first activity type is focused on what the crew would do to live in space: crew sleep, pre/post sleep activities to include galley operations and personal hygiene, exercise, review/development of crew planned activities/schedule. The second activity type is focused on science/payload operations and vehicle system management/maintenance, as required, and interaction with ground control center. During transit time, there will be no planned or contingency EVAs performed.

During surface operations, the crew would have ample time to plan and re-plan the surface activities, respond to problems, and readdress the scientific questions posed throughout the mission. The focus during this phase of the mission would be on the primary science and exploration activities. A general outline of crew activities would be established before the launch, but would be updated throughout the mission. This outline would contain detailed activities to ensure initial crew safety, make basic assumptions as to initial science activities, schedule periodic vehicle and system checkout, and plan for certain number of sorties. The crew will play a vital role in planning specific activities as derived from more general objectives defined on Earth.

Communication Delays

Expected communication delays between the crew and the ground control center will increase from zero during LEO to up to 6-8 minutes at Mars arrival with the same duration impact during return to Earth. During the Mars surface operations, these delays could go up to 22 minutes. Due to the communication delay, the crew is expected to perform autonomous operations as required.

Mars Surface Operations

Landing operations are expected to be fully automated with minimal crew interaction during the landing sequence, thereby minimizing the crew piloting skills and manual control capability. The crew will be in a recumbent position during all Entry, Descent, and Landing (EDL) operations. Current human health and support data indicate that it may take the crew a few weeks to acclimate to

the partial gravity of Mars after landing. After the crew has acclimated, initial surface activities would focus on transitioning from a "Lander mode" to a fully functional surface habitat. Once on the surface, expectations are that the crew will be required to perform many activities in support of mission objectives and mission success. During the entire 18-month stay on the Martian Surface, the six (6) crewmembers are expected to perform multiple EVAs. A key objective of the Mars surface mission is to get members of the crew into the field where they could interact as directly as possible with the planet that they have come to explore. This would be accomplished via the use of EVAs, assisted by pressurized and unpressurized rovers, to carry out field work in the vicinity of the surface base. Operationally, Mars surface EVAs would be conducted by a minimum of two people and maximum of four. If unpressurized rovers are used, an additional operational constraint would be imposed on the EVA team. If one rover is used, the EVA team would be constrained to operate within rescue range of the surface base. Taking multiple, and identical, rovers into the field allows the EVA team to expand its range of operations because these vehicles are now mutually supporting and thus able to handle a wider range of contingency situations

Crew Logistics/Food

The mission to Mars will consist of the crew habitation modules listed above (MPCV, Hab module, and Cargo module). All consumables and spare parts must be provided at the start of the mission and available from the habitable volume. The food that is carried aboard the transit habitat includes transit consumables needed for the round-trip journey plus contingency consumables required to maintain the crew should all or part of the surface mission be aborted. The crew would be forced to return to the orbiting vehicle, which would be used as an orbital "safe haven" until the Trans-Earth Insertion (TEI) window opens. Any contingency food remaining onboard the crewed vehicle would be jettisoned prior to the TEI burn to return home. The habitation module will have a food galley with the required capabilities for the crew to prepare their meals. Food storage will be contained in the cargo module under the required food storage constraints.

Resupply and Sample Return

There will not be any mission resupply considered to replenish the crew of logistical requirements. All monitoring for microbial or toxic hazards must be performed on board. No sample return will be possible.

Exercise Equipment

The crew will maintain their physiological health per the requirements as defined in NASA-STD-3001, Vol. 1.

HRP Constraints/Implied Requirements

- During Mars atmosphere entry (5-g), crew will be in a recumbent position until landing operations are complete. The vehicle design will not require the crew to be in an upright standing posture during entry.
- Countermeasures that support the Orthostatic Intolerance (OI) will be provided in support to any OI related events (e.g., Mars atmosphere entry).
- Adequate vehicle or habitat shielding, dosimetry, and operational procedures in place to prevent exposures above 30-day permissible dose limits.
- It is assumed that the Mars DRM will follow Level of Care Five standards in NASA-STD-3001 Vol. 1 for crewmember training and caliber: "The training and caliber of the caregiver shall be at the physician level, due to the exclusively autonomous nature of the mission."

Pre/Post Mission Assumptions

TBD post-flight Baseline Data Collection will still be required, but protocols will need to consider degree of crew de-conditioning after a 3-yr mission.

APPENDIX C – RESEARCH RATING

The HRP uses a research rating as a tool to communicate to Agency management the seriousness of a risk to crew health and performance when applied to the mission architecture and/or mission characteristics defined for each DRM. The research ratings serve as one of several inputs to determine the priority of each human risk, helping HRP Management make program decisions and allocate program resources.

Each research rating is derived by comparing the current state of knowledge about a risk, whether existing standards are defined and met, and the degree to which research will improve the current risk posture with respect to crew health and performance during long duration missions. Each human risk has one of four research ratings identified for each of the four DRMs, driven by its applicability to the DRM mission architecture and/or mission characteristics. HRP uses the following four DRMs to bound its exploration mission assumptions: (1) 12-month mission on ISS (ISS-12); (2) Lunar (Outpost) mission; (3) NEA mission; and (4) Mars mission [Appendix B of this document for further definition and assumptions for each DRM].

The four possible research ratings are: *Controlled, Acceptable, Unacceptable,* and *Insufficient Data*. These ratings are described below.

Rating: Controlled (C) - Green
A risk is deemed to have a research rating of ***Controlled*** if based on available evidence, the projected mission architecture (with assumptions on DRM-specific vehicle design and operations constraints) meet existing standards for maintaining crew health and performance and countermeasures exist to control the risk. Continued research or technology development will improve capabilities, provide additional trade space to support meeting crew health standards or ensure that vital Agency core competencies are accessible.

Context:
The scientific, operational and clinical evidence for the risk and current available mitigations and countermeasure capabilities demonstrate that the Agency can meet the existing standards for maintaining crew health and performance during all phases of the mission. Research has provided at least one solution capability to address the risk. Additional research or technology development could further reduce risk by enhancing understanding and offering different options to increase engineering and operational efficiencies, make the best use of unique assets such as ISS in optimizing risk posture, and maintain vital Agency core competencies.

Rating: Acceptable (A) - Yellow
A risk is deemed to have a research rating of ***Acceptable*** if based on available evidence, the projected mission architecture (with assumptions on DRM-specific vehicle design and operations constraints) likely provides the capability to meet existing standards for maintaining crew health and performance but the risk is not fully controlled. The remaining level of uncertainty would likely lead the Agency to accept a higher than expected level of risk to crew health and performance during some phases of the mission. Continued research or technology development is expected to improve capabilities or substantiate crew health standards.

Context:
The scientific, operational and clinical evidence for the risk and current available mitigation and countermeasure capabilities demonstrate that the Agency can likely meet existing standards for maintaining crew health and performance during some, but not all phases of the mission. Additional research or technology development may further improve the risk research rating to achieve a *Controlled* rating.

Rating: Unacceptable (U) - Red
A risk is deemed to have a research rating of ***Unacceptable*** if based on available evidence, the projected mission architecture (with assumptions on DRM-specific vehicle design and operations constraints) will not provide the capabilities required to meet existing standards for maintaining crew health and performance during all phases of the mission. Therefore, research is required to acquire necessary information and develop necessary capabilities and countermeasures to arrive at an acceptable risk posture.

Context:
The scientific, operational and clinical evidence for the risk and current available mitigations and countermeasure capabilities do not adequately demonstrate the capability of the Agency to meet existing standards to protect and/or maintain crew health and performance during all phases of the mission. The inadequacy and uncertainty in the risk mitigation capabilities and countermeasures will require additional data and/or mitigation strategies to be developed through the research performed by the HRP.

Rating: Insufficient Data (I) - Gray
A risk is deemed to have a research rating of ***Insufficient Data*** if there is not enough available evidence to assess whether the projected mission architecture (with assumptions on DRM-specific vehicle design and operations constraints) can meet existing standards for crew health and performance or if such standards need to be developed. Research is required to further understand and define the risk to the point that its research rating can be determined by HRP to

controlled, acceptable or unacceptable. This rating is primarily for new risks before a research rating can be determined.

Context:
The scientific, operational and clinical evidence for the risk and current mitigation and countermeasures capabilities are inadequate to allow the assessment of the ability of the mission architecture and/or mission characteristics to support crew health and performance standards. Additional research is expected to support determination of a new research rating.

The research rating of a risk alone is not sufficient to determine its priority within the HRP research portfolio. Priority is dependent on other factors such as limited availability of certain necessary resources (as the ISS, ground analogs, etc.), program funding, exceptionally long lead times (e.g., needed to improve understanding and mitigation of radiation risks), or the amount of risk reduction that can be obtained with a specific set of resources. The level of activity (or budget) and timing of research investments reflect the final prioritization of the risks.

Table C-1 summarizes key aspects of each research rating. It is intended as a guideline, not as an absolute set of aspects required to determine assignment to a particular rating.

Table C-1 – Summary of Research Rating Key Aspects

Aspect	Controlled (Green)	Acceptable (Yellow)	Unacceptable (Red)	Insufficient (Gray)
Existence of Relevant Standards or Requirements	Exist	Exist	Exist	Need to be developed
Ability to Meet Existing Relevant Standards or Requirements	Mission architecture meets all phases	Mission architecture likely meets, but with high uncertainty for at least one mission phase	Mission architecture likely will not meet all phases	There is not enough information to assess the likelihood the mission architecture meets all phases

Table C-1 – Summary of Research Rating Key Aspects

Aspect	Controlled (Green)	Acceptable (Yellow)	Unacceptable (Red)	Insufficient (Gray)
Time Required for Risk Closure vs. When Closure is Needed	Time available with margin	Adequate time available	Inadequate time available	Unable to assess
Availability of Required Facility Resources	Available	Limited availability	Limited availability	Unable to assess
Maintenance of Core Competencies Required	Other maintenance opportunities available	Limited other maintenance opportunities	Limited other maintenance opportunities	Unable to assess
Primary Category of Consequence for Not Meeting Standards or Requirements	Health During Mission, Health Post-Mission, or Performance During Mission	Health During Mission, Health Post-Mission, or Performance During Mission	Health During Mission, Health Post-Mission, or Performance During Mission	Health During Mission, Health Post-Mission, or Performance During Mission

Table C-2 contains each HRP risk, the HRP Element to which it is assigned, the research ratings for each risk as they apply to the DRMs, and the rationale for the research ratings.

Table C-2 – HRP Research Rating Matrix

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Orthostatic Intolerance During Re-Exposure to Gravity (Short Title: OI) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12, Lunar, and NEA DRMs, and "Acceptable" for the Mars DRM. Existing countermeasures (e.g., fluid loading, re-entry compression garments, active cooling, ground support personnel) have been successfully implemented on ISS. The post-flight compression garments are expected to be sufficient for the return to Earth gravity after ISS-12, Lunar and NEA missions; however, there is greater uncertainty regarding compression garment effectiveness upon return from Mars concerning the re-entry profile, and the exposure of the crew to Earth's gravity, especially if medical support is not available immediately upon landing. Of greatest concern is a possible water landing, which could lead to a "stable two landing configuration" (crewmembers are upside down) and/or the possibility of pharmaceutical usage to control sea sickness. Data shows that usage of the most common drug for motion sickness causes orthostatic hypotension in 100% of subjects tested (Shi, 2011).*	C	C	C	A
HHC	Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Acceptable" for all DRMs. Current exercise loading devices [e.g., the Advanced Resistive Exercise Device (ARED)] appear to mitigate bone mineral density (BMD) loss for 6-month ISS flights, but the time course of loss, and the structural distribution of bone mass in whole bone and between bone compartments are unknown. The current standards are based solely on BMD T-scores; BMD alone is no longer an accepted diagnostic criterion of Osteoporosis (a medical condition). Therefore, the current standards require modification in order to sufficiently meet NASA's requirements for protecting against this risk.* *The measurement of cortical thickness, trabecular BMD and minimum femoral neck width of the hip by Quantitative Computed Tomography (QCT) are predictors of hip fracture above and beyond Dual-energy X-ray Absorptiometry (DXA) BMD (Black et al, JBMR 2008). Hence, surveillance of these sites of the hip has been recommended by clinical panel to …* *(continued)*	A	A	A	A

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo) *(concluded)* *…evaluate if declines due to spaceflight might combine with expected changes due to aging . Surveillance data are also required for clinical practice guidelines to be formulated, i.e., identifying <u>when</u> a countermeasure is most critical (preflight, in-flight, postflight or with long-term health management). Research is required to validate emerging technologies for the spine. In addition, a major technology effort is required to supply validated loads and countermeasures capabilities in the confines of exploration vehicles. The efficacy of all countermeasures shall be established by maintenance of bone compartments of the hip. Current ARED exercise as a countermeasure remains to be validated by this method. The QCT surveillance method is being researched prior to its acceptance as an Medical Requirements Integration Documents (MRID) enhancement. These spaceflight-induced changes to astronauts' hip and spine (clinically relevant sites for fragility fractures) need to be monitored after missions to evaluate recovery to preflight status; the failure to see recovery by two years post mission is a clinical trigger for possible intervention.*	A	A	A	A
HHC	Risk Factor of Inadequate Nutrition (Short Title: Nutrition) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and Lunar DRMs, "Acceptable" for NEA DRM, and "Unacceptable" for the Mars DRM. The nutrition risk is directly tied to the food risk and there exists a stable food system for ISS-12 (stability and variety of the food, defined ground processing techniques, periodic resupply) and Lunar missions. There does not exist a food system that can meet the crew's nutrition needs for a Mars duration mission. For NEA mission, a number of factors lead to an "Acceptable" rating, including: 30-day surface operations (multiple EVAs) will likely hinder food intake, and will increase stress (oxidative and otherwise). There will be no resupply of food, and this is a 1 year closed food system mission, with associated increase in risks beyond ISS-12. While these issues also impinge on Lunar Outpost missions, at this point the proximity, the shorter duration (6 months), alternating day EVAs, and potential for some resupply have kept this as "Controlled."*	C	C	A	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems (Short Title: EVA) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Acceptable" for all DRMs. The risk of injury or reduced performance due to the EVA suit is directly related to the design of the suit, but is also a function of the fitness and EVA skillset of the crewmember. It requires a balance between functionality/dexterity and the impact of the suit on the human. Increasing demand on suit functionality may be correlated with increased injury from the suit. New suit technologies are required to reduce injury, while maintaining or improving performance. EVA operational concepts for Exploration mission are not well understood.*	A	A	A	A
HHC	Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 , "Acceptable" for Lunar and NEA DRMs, and "Unacceptable" for the Mars DRM. While ARED results are initially promising, some crew members still do not meet the applicable standard. Optimization of countermeasures (protocols and hardware) are required in order to a) minimize loss of muscle mass and strength, b) understand the loads required to protect all or at least the vast majority of crew members and c) inform new exercise hardware design. An improved understanding of the time course of muscle loss is required to address countermeasures needs for DRMs that are substantially longer in duration than our current experience base (i.e. ISS-6).* *It is still unknown whether a treadmill is absolutely required, and if it is, what are the minimal treadmill capabilities?*	C	A	A	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Renal Stone Formation (Short Title: Renal) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs. There exist crew selection standards, clinical guidelines, and a suite of effective countermeasures (e.g., hydration, dietary counseling, reduction of salt in meals) to help mitigate this risk. In addition, the actual incidence of inflight renal stone clinical disease is very low, with one unconfirmed case in all of human spaceflight. Although mitigation strategies are well known, the ability to treat a renal stone during a NEA or Mars mission is not yet available. Continued research work can support development of a treatment capability should a renal stone occur during a NEA or Mars DRM.*	C	C	C	C
HHC	Risk of Bone Fracture (Short Title: Fracture) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and NEA DRMs and "Acceptable" for Lunar and Mars DRMs. Current exercise loading devices (e.g., ARED) appear to mitigate BMD loss for 6-month ISS flights, but the time course of loss, and the structural distribution of bone mass in whole bone and between bone compartments are unknown. Because BMD does not capture changes in bone size and geometry, and bone strength is a function of how the mass is distributed from neutral axis, BMD measurements do not accurately assess the impact of countermeasures on bone's ability to resist fracture loads. In addition, the current standard is not based upon BMD loss but upon BMD T-scores. A T-score identifies the relative risk for fracture, it does not identify who will fracture – analogous to high blood pressure and stroke risk. Furthermore, the standards do not state, but it is implied in NASA-STD-3001, that BMD is for hip and lumbar spine. Fractures however could occur at other sites - for which there is no standard. Bone loss in space is specific for certain skeletal regions; thus, one cannot assume protection at hip and spine protects other sites. Therefore, until the current standards are modified to sufficiently meet NASA's requirements for protecting against this risk , countermeasure efficacy is not fully known. Countermeasures should be evaluated for ability to mitigate declines in bone strength and not a surrogate for bone strength, i.e., BMD. In order to update current standards appropriately, further research is required.* *(continued)*	C	A	C	A

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Bone Fracture (Short Title: Fracture) *(concluded)* *This risk is considered "Controlled" for the ISS-12 and NEA DRMs due to the weightless environment (the low probability of encountering a traumatic load) and a past history of a low incidence of fracture during spaceflight for the ISS-6 DRM and Mir missions that were close in duration to the ISS-12 and NEA DRMs. This risk is considered "Acceptable" for the Lunar and Mars DRMs due to the unknown, but higher probability of accidents and potential for traumatic loads to bone. The decline in bone strength alone is not perceived to be the major contributing factor to the fracture risk relative to excessive loading, However, a decline in human performance may increase the risk for accidents due to the collective impact of muscular atrophy, vision impairment, disruptions in gait and neuromuscular control, combined with planned physical activity, unexplored terrains and human behavior. In addition, a major technology effort is required to supply validated loads and countermeasures capabilities in the confines of exploration vehicles.*	C	A	C	A
HHC	Risk of Intervertebral Disc Damage (Short Title: IVD) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Insufficient" for all DRMs. The risk factors that put astronauts at an increased risk for IVD are currently unknown [e.g., is it related to preflight health of intervertebral disc (IVD), degradation during mission, or loading during return to gravity]; these risk factors need to be explored. Furthermore, although there appears to be a correlation between IVD damage and spaceflight, a causal relationship has yet to be definitively established (for example, does exposure to microgravity cause degradation to IVD because IVD elongation prevents the influx of nutrients and outflux of toxins to be exchanged?). Also, insufficient information exists to determine the relationship between duration of spaceflight and incidence of IVD damage.*	I	I	I	I
HHC	Risk of Cardiac Rhythm Problems (Short Title: Arrhythmia) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the Lunar DRM, "Acceptable" for the ISS-12 DRM, and "Insufficient Data" for the NEA and Mars DRM's. For…* *(continued)*	A	C	I	I

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Cardiac Rhythm Problems (Short Title: Arrhythmia) *(concluded)* *…ISS-12 and NEA there is greater uncertainty in the time curve for the QT prolongation currently observed in ISS-6 missions. The QT interval can further be lengthened by pharmaceuticals in the med kit. ISS-12 is considered "Acceptable" because of the ability for an emergency return to Earth, while this evacuation ability is not available during NEA missions. Furthermore, increased exposure to radiation may increase risk of atherosclerotic disease, which could impact cardiac electrophysiology (in the event of myocardial infarction). Longer missions such as Mars cannot be assessed without data on the time course of cardiac changes.*	A	C	I	I
HHC	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Short Title: Aerobic) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and Lunar DRM, "Acceptable " for NEA, and "Unacceptable" for the Mars DRM. An "Acceptable " risk posture for Mars DRM would require a level of countermeasure maturity whereby all (or the vast majority of) crewmembers on an ISS-6 missions would be expected to meet the Standard. This is not unequivocally the case as of yet. Furthermore, smaller exploration class aerobic exercise hardware would be required to accomplish this during a Mars mission. It is still unknown whether a treadmill is absolutely required, and if it is, what are the minimal treadmill capabilities?*	C	C	A	U
HHC	Risk of Crew Adverse Health Event Due to Altered Immune Response (Short Title: Immune) *Rating Rationale: The research rating for this risk has been determined by HRP to be: "Controlled" for the ISS-12 and Lunar Sortie missions; and "Acceptable" for the Lunar Outpost, NEA and Mars DRM. The in-flight status of the human immune system is still being determined via multiple current ISS studies. Validation of a monitoring strategy and countermeasures is necessarily deferred until the in-flight status is understood. However, some data exists demonstrating in-flight alterations in adaptive immunity and stress/viral reactivation, meaning this is not merely a post-flight phenomenon. The dysfunction appears to persist for the duration of a 6-month ISS mission, but primarily in an asymptomatic fashion. Based on a…* *(continued)*	C	A	A	A

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Crew Adverse Health Event Due to Altered Immune Response (Short Title: Immune) *(concluded)* *…recent analysis of Integrated Medical Model (IMM) Clinical Findings Forum (CLiFF) and crew medical data, there is incidence of immune-related disorders on-orbit at 4.22 medical events for ISS crew year. It is reasonable to conclude ISS-12 missions will not pose a serious clinical risk to crewmembers, and Lunar Sortie missions are likely to be of insufficient duration to substantially raise clinical risk due to immune dysregulation. For all missions beyond LEO, with no rapid return option, deep-space radiation exposure, elevated physiological stress and limited clinical care (compared to terrestrial), an increase in immune-related clinical risk is likely without countermeasures. Additional unique immunological influences during surface lunar deployment include lunar dust exposure (lung), recently demonstrated to induce a persistent inflammatory response in an animal model. This statement is based on the current in-flight evidence regarding diminished immune function in crewmembers, a phenomenon that persists during long-duration spaceflight.*	C	A	A	A
HHC	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with Space Flight (Short Title: Sensorimotor) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12, Lunar, and NEA DRMs, and "Acceptable" for the Mars DRM. For ISS-12, Lunar, and NEA missions the primary mitigation of ground personnel support for the crew during landings remains available. For Mars the uncertainty is the knowledge gap on the crew's ability to perform surface operations after a Mars landing without the Earth ground personnel support.*	C	C	C	A

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Clinically Relevant Unpredicted Effects of Medication (Short Title: Pharm) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12, Lunar, and NEA DRMs, and "Unacceptable" for the Mars DRM. There exists a stable medication system for ISS-12 (e.g., shelf life), plus there is resupply capability for the ISS-12 mission. Lunar and NEA missions are of shorter or comparable durations to ISS-12. There does not exist a medication system that can meet the crew's needs for a Mars duration mission. Mars is "U" because a 3-year mission , combined with pre-launch packing and purchasing, exceeds the shelf life of most medications. Provided that procurement of fresh medications is possible, and that permitted mass and volume are adequate to use packaging that maximizes medication stability, the other (shorter) missions will have within-date medications.*	C	C	C	U
HHC	Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (Short Title: VIIP) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Unacceptable" for ISS-12, NEA, and Mars DRMs and "Insufficient" for Lunar. This has been identified as an issue from past ISS-6 missions, and there is a knowledge gap to understanding the causative mechanisms of this constellation of anatomical and visual changes. The risk for ISS-6 should also be considered to be insufficient given that full characterization of the effects of the Visual Impairment/Intracranial Pressure (VIIP) syndrome is pending (e.g., post mission OCT and visual field testing has not occurred in those who have developed papilledema). Also, no countermeasures exist today and one or more may be required to enable long duration missions (>6 months microgravity). Limited crewmembers that meet medical criteria may be available for exploration type missions without countermeasures. These factors could likely result in the OCHMO recommending to Agency Management against the implementation of a mission architecture without further understanding and/or countermeasures. Since VIIP is now a factor in crew assignment criteria for ISS-6 missions, further research is required to acquire necessary information and develop necessary capabilities and countermeasures to arrive at an acceptable risk posture.Lunar missions are rated as "insufficient" as we are unable to quantify the protective nature of the Lunar gravity environment at this time.*	U	I	U	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Decompression Sickness (Short Title: DCS) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs. Existing countermeasures (e.g., prebreathe protocols) are adequate for the ISS missions. For a new EVA architectures, forward work would be required to validate any changes to prebreathe and decompression protocols, but the procedures in place to control risk of DCS are understood.*	C	C	C	C
HHC	Risk of Injury from Dynamic Loads (Short Title: Occupant Protection) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 DRM, "Acceptable" for Lunar and NEA DRMs, and "Insufficient" for the Mars DRM. There exist standards and defined requirements that were intended to be used to design appropriate protection for the crew, however these standards should be revised and refined to ensure that future landing vehicles (including Orion) can meet the intent of these standards (to mitigate injury to crewmembers caused by accelerations during dynamic mission events). Gaps and risks may be readdressed as specific exploration mission architectures are identified. Lessons learned data from past crew mishaps is available and informs these research ratings where applicable. For ISS-12 DRM: While there may be an increased risk of injury during dynamic mission phases (e.g., landing) compared to ISS-6 missions due to likely increased deconditioning, this DRM is assumed "Controlled" based on past success of landing crewmembers with mission durations close to or greater than 1 year in Soyuz vehicles (Mir missions). Also taken into consideration is past crew landing data for ISS-6 pre-ARED missions (likely more deconditioning than post-ARED 6-month missions) in Soyuz vehicles.*	C	A	A	I

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SHFH	Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System (Short Title: Food) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and Lunar DRMs, "Acceptable" for the NEA DRM, and "Unacceptable" for the Mars DRM. There exists a stable food system for ISS-12 (stability and variety of the food, defined ground processing techniques, periodic resupply) and Lunar missions. The food risk is directly tied to the nutrition risk factor and an acceptable rating has been determined for both risks for the NEA mission. A number of factors lead to an "Acceptable" rating, including: 30-d surface ops (greater EVA demand) will likely hinder food intake, and will increase stress (oxidative and otherwise). There will be no resupply of food including fresh foods higher in antioxidants and vitamins, and this is a one year closed food system mission, with associated increase in risks beyond ISS-12. While these issues also impinge on Lunar Outpost missions, at this point the proximity, the shorter duration (6 mos), alternating day EVAs, and potential for some resupply have kept this as "Controlled." There does not exist a food system that can meet the crew's food needs for a Mars duration mission.*	C	C	A	U
SHFH	Risk of Inadequate Human-Computer Interaction (Short Title: HCI) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs, to the extent that we understand the spacecraft and mission designs for those DRMs. There exist standards and defined requirements for spacecraft crew interfaces that are appropriate for operational environments similar to ISS. Though controlled, there is uncertainty regarding the adequacy of the current state-of the-art of HCI associated with autonomous operations required when small crews in dynamic situations have communication delays with Earth. The adequacy of HCI with onboard training systems, and automation and robotic operations for Mars will also remain uncertain until we better understand those needs. These concerns are represented by the research ratings in the Train and HARI risks. As HCI performance data are collected during ISS-12, Lunar and NEA missions, and more is understood about the Mars missions, the research rating may be evaluated and adjusted.*	C	C	C	C

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SHFH	Risk of Performance Errors Due to Training Deficiencies (Short Title: Train) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for ISS-12, Lunar, and NEA DRMs and "Acceptable" for the Mars DRM, to the extent that we understand the spacecraft and mission designs for those DRMs. For ISS-12 there exist adequate countermeasures (e.g., verifying task design through ground resources such as simulators) and operational controls (e.g., checklists), plus the ability for real-time ground support assistance. For Lunar and NEA there will be fewer time-critical tasks (i.e., spacecraft docking), and we can define tasks adequately and work through issues that arise based on past experiences on ISS missions. Though acceptable, there is uncertainty regarding workload levels during autonomous missions when small crews in dynamic situations have communication delays with Earth. The adequacy of current state-of the-art task, schedule, and procedure designs for Mars will also remain uncertain until we better understand those needs. As task performance data are collected during ISS-12, Lunar and NEA missions, and more is understood about the Mars missions, the research rating may be evaluated and adjusted.*	C	C	C	A
SHFH	Risk of Inadequate Design of Human and Automation/Robotic Integration (Short Title: HARI) *Rating Rationale: The research rating ratings for this risk have been determined by HRP to be "Controlled" for the ISS-12, Lunar, and NEA DRMs, and "Acceptable" for the Mars DRM. Existing design requirements and operational controls have demonstrated their adequacy for the ISS-12 mission. Lunar and NEA have similarities to the ISS missions with existing robotics integration and assume no appreciable communication delay. Uncertainty for Mars is due to increased distance for ground support of recovery from errors, increased mission duration, increased reliance on automation and robotics (including for EVA support), and more dynamic phases of flight such as landings or dockings that require proper integration with automation and robotics.*	C	C	C	A

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SHFH	Risk of Inadequate Critical Task Design (Short Title: Task) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs, to the extent that we understand the spacecraft and mission designs for those DRMs. For ISS-12 there exist adequate countermeasures (e.g., verifying task design through ground resources such as simulators) and operational controls (e.g., checklists), plus the ability for real-time ground support assistance. For Lunar and NEA there will be fewer time-critical tasks (i.e., spacecraft docking), and we can define tasks adequately and work through issues that arise based on past experiences on ISS missions. Though controlled, there is uncertainty regarding workload levels during autonomous missions when small crews in dynamic situations have communication delays with Earth. The adequacy of current state-of the-art task, schedule, and procedure designs for Mars will also remain uncertain until we better understand those needs. As task performance data are collected during ISS-12, Lunar and NEA missions, and more is understood about the Mars missions, the research rating may be evaluated and adjusted.*	C	C	C	C
SHFH	Risk of Adverse Health Effects of Exposure to Dust and Volatiles During Exploration of Celestial Bodies (Short Title: Dust) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Acceptable" for the Lunar DRM, and "Insufficient Data" for the NEA and Mars DRMs. Note that this risk is not applicable to the ISS missions due to its focus on celestial bodies. While knowledge is available for Lunar based on past lunar mission experiences, more efficient Environmental Control and Life Support System (ECLSS) technologies are required to completely control the risk. For NEA and Mars, uncertainty is due to the lack of evidence available to characterize the properties of the dusts and volatiles for these destinations, and therefore the ability to predict the clinical impacts on humans.*	N/A	A	I	I

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SHFH	Risk of an Incompatible Vehicle/Habitat Design (Short Title: Hab) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12, Lunar and NEA DRMs, and "Acceptable" for the Mars DRM. Human factors accommodations for ISS are already captured in existing standards. Lunar and NEA are "Controlled" based on past experience designing vehicles for manned spaceflight missions and incorporation of lessons learned. For Mars the uncertainty in addressing issues related to expected volume constraints is exacerbated by the longer duration mission.*	C	C	C	A
SHFH	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions (Short Title: Microhost) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and Lunar DRMs. It has been determined to be "Acceptable" for the NEA and Mars DRMs. For ISS-12 and Lunar there is historical microbial monitoring, current operational and vehicle design mitigation techniques, and availability of antibiotic countermeasures. For NEA and Mars there is uncertainty in microbial diversity and virulence in longer duration missions*	C	C	A	A
ExMC	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities (Short Title: ExMC) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 DRM, "Acceptable" for the Lunar and NEA DRMs, and "Unacceptable" for the Mars DRM. The medical system and suite of countermeasures that would be needed to support human health for an ISS 12-month mission are well-understood. Additionally, the Integrated Medical Model (IMM) is baselined to ISS medical capabilities and can be leveraged by mission planners as a decision support tool.* *NEA and Lunar: Acceptable* *Based on analysis performed using the IMM, it is anticipated that the medical capabilities needed to support human health will be available for these missions. The conditions predicted to influence the overall health status of the crew include: space adaptation conditions (for example, space motion …* *(continued)*	C	A	A	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
ExMC	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities (Short Title: ExMC) *(continued)* *…sickness and nasal congestion) in the early portion of the mission, conditions arising from frequent EVA (for example, fingernail delamination and paresthesias), and other conditions such as skin abrasions, eye abrasions, and exposed pulp. Conditions strongly influencing the evacuation likelihood include: dental conditions,systemic infection (sepsis), decompression sickness, smoke inhalation, and toxic exposure. The conditions strongly influencing the loss of crew life likelihood include: decompression sickness, systemic infections (sepsis), and smoke inhalation. It should be noted that the current analysis includes some medical conditions that are consequences of vehicle risks (for example, fire leading to the medical condition of smoke inhalation). Among the capabilities being developed to address this risk are: in-flight renal stone treatment, upgraded dental capabilities, and advanced medical system infrastructures (including electronic medical records, consumables tracking, and smart peripherals).* *Mars: Uncontrolled* *Further research is needed to develop the medical capabilities needed to support human health on a Mars mission. Based on analysis from the IMM, the conditions predicted to influence the overall health status of the crew include: conditions arising from frequent EVA (for example, decompression sickness, fingernail delamination and paresthesias) and other conditions such as skin abrasions, eye abrasions, and exposed pulp. Conditions strongly influencing the evacuation likelihood include: dental conditions, systemic infection (sepsis), decompression sickness,smoke inhalation, and toxic exposure. The conditions strongly influencing the loss of crew life likelihood include: decompression sickness, systemic infections (sepsis), and smoke inhalation. It should be noted that the current analysis includes some medical conditions that are consequences of vehicle risks (for example, fire leading to the medical condition of smoke inhalation). Among the capabilities being developed to address this risk are: in-flight renal stone treatment, upgraded dental capabilities, and advanced medical system infrastructures (including electronic medical records, consumables tracking, and smart peripherals).* *(continued)*	C	A	A	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
ExMC	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities (Short Title: ExMC) *(concluded)* *Uncertainty in the ratings is driven by the known or anticipated occupational hazards associated with long duration exposure to weightlessness and surface activity in partial gravity fields, gaps in our knowledge of the actual occupational medical issues associated with these activities, and extreme remoteness driving the need for complete autonomy in medical support.*	C	A	A	U
BHP	Risk of Adverse Behavioral Conditions and Psychiatric Disorders (Short Title: Bmed) - *Reference RMATs for Risk of Adverse Behavioral Conditions, and Risk of Psychiatric Disorders* *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 and Lunar DRMs, "Acceptable" for the NEA DRM, and "Unacceptable" for the Mars DRM. For ISS-12 there is anecdotal evidence that the crew has been successful at thriving in the ISS environment. There exist effective countermeasures (e.g., support services from operational psychology personnel). For NEA and Mars, mission duration and distance from Earth (remoteness) are the major stressors. (Based on 2009 space flight experience and terrestrial analogs (especially Antarctica).*	C	C	A	U
BHP	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs. Some existing countermeasures (e.g., work with ground control regarding scheduling and phase shifting, multiple layers of accountability when conducting critical tasks, education for ground crews) have been successfully implemented for ISS operations. While the risk of fatigue-related performance errors is considered controlled, there is uncertainty in the likelihood and consequence of performance decrements for crews in Lunar, NEA, and Mars missions. The autonomous operations anticipated for a NEA and Mars mission will change the ways through which crews conduct tasks, leaving them more vulnerable to fatigue related performance errors. Additionally, constrained volume increases the likelihood of sleep disturbances, and the chronic…* *(continued)*	C	C	C	C

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
BHP	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep) (concluded) *…stressors of remote missions can lead to sleep loss. As sleep and fatigue data are collected during ISS-12, Lunar and NEA missions, and more information is understood about NEA and Mars mission scenarios, the research rating may be evaluated and adjusted.*	C	C	C	C
BHP	Risk of Performance Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Short Title: Team) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the Lunar DRM, and "Acceptable" for the ISS-12, NEA and Mars DRMs. For ISS-12 there is greater uncertainty in the stability of team dynamics in a longer duration mission. For NEA and Mars, mission duration and distance from Earth (remoteness) are the major stressors. (Based on 2009 space flight experience and terrestrial analogs (especially Antarctica)*	A	C	A	A
SR	Risk of Radiation Carcinogenesis (Short Title: Cancer) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for the ISS-12 DRM, "Acceptable" for the Lunar DRM, and "Unacceptable" for the NEA and Mars DRMs. For ISS-12 there exist standards for exposure limits and it has been demonstrated those limits are achievable based on ISS experience. For other DRMs beyond low earth orbit, minimal protection is available from Galactic Cosmic Rays (GCR), thus mission durations are limited. Planetary protection from Lunar surface is sufficient to support 4 to 6-month lunar missions. Risk rating is highly dependent on lunar mission duration and time in solar cycle. Rating changes from controlled during short lunar sortie type missions to acceptable as mission durations approach six months. There are some circumstances in which ratings may become unacceptable, especially for younger female crew members and for crew members with previous mission exposures. NEA and Mars missions…* *(continued)*	C	A	U	U

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SR	Risk of Radiation Carcinogenesis (Short Title: Cancer) (concluded) *…do not offer sufficient protection during transit stages, thus exposure limits are reached before these missions could be completed. Further radiobiology research is required to reduce uncertainties in risk projections in addition to providing integrated mitigation strategies and countermeasures to move NEA and Mars ratings from unacceptable to acceptable. These DRM assessments are for single missions only and different ratings may apply if a crew member flies on multiple missions.*	C	A	U	U
SR	Risk of Acute Radiation Syndromes Due to Solar Particle Events (Short Title: ARS) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Controlled" for all DRMs. For all missions there will be adequate shielding provided by the vehicle or habitat, dosimetry, and operational procedures to minimize exposures. For ISS-12 additional protection is also provided by the Earth's magnetosphere and real-time ground support is available for monitoring. It is assumed that research on acute exposures will continue to evaluate the appropriateness of the skin dose Permissible Exposure Limit (PEL) and for countermeasure development in the event of accidental exposure.*	C	C	C	C
SR	Risk of Acute or Late Central Nervous System Effects from Radiation Exposure (Short Title: CNS) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Acceptable" for the ISS-12 and Lunar DRMs, and "Insufficient Data" for the NEA and Mars DRMs. Although ISS and Lunar mission exposures are expected to meet CNS PELs as currently written, the relative biological effectiveness of the space environment on CNS effects is largely unknown. As exposures levels increase with longer mission durations (multiple missions, NEA, Mars), animal data suggest low doses of high energy particles (HZE) particles similar to exposure levels of these DRMs may cause detrimental CNS effects and there is insufficient knowledge to extrapolate these results to crew. Further radiobiology research is required to understand these risks and to develop mitigation strategies if necessary in order to move ratings into an acceptable or controlled status. These DRM assessments are for single missions only and different ratings may apply if a crewmember flies on multiple missions.*	A	A	I	I

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
SR	Risk of Degenerative Tissue or other Health Effects from Radiation Exposure (Short Title: Degen) *Rating Rationale: The research rating for this risk has been determined by HRP to be "Acceptable" for the ISS-12 and Lunar DRMs, and "Insufficient Data" for the NEA and Mars DRMs. Although ISS and lunar mission exposures are expected to meet circulatory system PELs as currently written, a level of uncertainty still exists on the relative biological effectiveness of the space environment on the risk of circulatory diseases as well as digestive diseases. As exposures levels increase with longer mission durations (multiple missions, NEA, Mars), human epidemiology data suggests low doses of low Linear Energy Transfer (LET) radiation within range of exposure levels of these DRMs may cause degenerative effects and there is insufficient knowledge to extrapolate these results to crew. Further radiobiology research is required to understand these risks and to develop mitigation strategies if necessary in order to move ratings into an acceptable or controlled status. It should be noted that this risk is a grouping of potential risks, one of which is well understood (cataracts) and for the others there is a paucity of research data. These DRM assessments are for single missions only and different ratings may apply if a crew member flies on multiple missions.*	A	A	I	I

Table C-3 is a 1-page summary of HRP human health and performance risks and their associated research ratings for each DRM. This table is provided as a "quick-look" assessment of the risk research posture for the program.

Table C-3 – One Page Summary of HRP Risks

HRP Element	Risk Title (Short Title)	HRP Research Rating			
		ISS-12	Lunar	NEA	Mars
HHC	Risk of Orthostatic Intolerance During Re-Exposure to Gravity (Short Title: OI).	C	C	C	A
HHC	Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo)	A	A	A	A
HHC	Risk Factor of Inadequate Nutrition (Short Title: Nutrition)	C	C	A	U
HHC	Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems (Short Title: EVA)	A	A	A	A
HHC	Risk of Inadequate Performance Due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle)	C	A	A	U
HHC	Risk of Renal Stone Formation (Short Title: Renal)	C	C	C	C
HHC	Risk of Bone Fracture (Short Title: Fracture)	C	A	C	A
HHC	Risk of Intervertebral Disc Damage (Short Title: IVD)	I	I	I	I
HHC	Risk of Cardiac Rhythm Problems (Short Title: Arrhythmia)	A	C	I	I
HHC	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Short Title: Aerobic)	C	C	A	U
HHC	Risk of Crew Adverse Health Event Due to Altered Immune Response (Short Title: Immune)	C	A	A	A
HHC	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with Space Flight (Short Title: Sensorimotor)	C	C	C	A
HHC	Risk of Clinically Relevant Unpredicted Effects of Medication (Short Title: Pharm)	C	C	C	U
HHC	Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations (Short Title: VIIP)	U	I	U	U
HHC	Risk of Decompression Sickness (Short Title: DCS)	C	C	C	C
HHC	Risk of Injury from Dynamic Loads (Short Title: Occupant Protection)	C	A	A	I
SHFH	Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System (Short Title: Food)	C	C	A	U
SHFH	Risk of Inadequate Human-Computer Interaction (Short Title: HCI)	C	C	C	C
SHFH	Risk of Performance Errors Due to Training Deficiencies (Short Title: Train)	C	C	C	A
SHFH	Risk of Inadequate Design of Human and Automation/Robotic Integration (Short Title: HARI)	C	C	C	A
SHFH	Risk of Inadequate Critical Task Design (Short Title: Task)	C	C	C	C
SHFH	Risk of Adverse Health Effects of Exposure to Dust and Volatiles During Exploration of Celestial Bodies (Short Title: Dust)	N/A	A	I	I
SHFH	Risk of an Incompatible Vehicle/Habitat Design (Short Title: Hab)	C	C	C	A
SHFH	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions (Short Title: Microhost)	C	C	A	A
ExMC	Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities (Short Title: ExMC)	C	A	A	U
BHP	Risk of Adverse Behavioral Conditions and Psychiatric Disorders (Short Title: Bmed) - *Reference RMATs for Risk of Adverse Behavioral Conditions, and Risk of Psychiatric Disorders*	C	C	A	U
BHP	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep)	C	C	C	C
BHP	Risk of Performance Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Short Title: Team)	A	C	A	A
SR	Risk of Radiation Carcinogenesis (Short Title: Cancer)	C	A	U	U
SR	Risk of Acute Radiation Syndromes Due to Solar Particle Events (Short Title: ARS)	C	C	C	C
SR	Risk of Acute or Late Central Nervous System Effects from Radiation Exposure (Short Title: CNS)	A	A	I	I
SR	Risk of Degenerative Tissue or other Health Effects from Radiation Exposure (Short Title: Degen)	A	A	I	I